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MONTEREY, CALIFORNIA

THESIS

**QUANTIFYING THE BENEFIT OF FACILITY-BASED
MIXED REALITY TRAINING IN SUPPORT OF THE FITE
JCTD BUSINESS CASE ANALYSIS**

by

Chez Yee Ang

December 2009

Thesis Advisor:
Second Reader:

Daniel A. Nussbaum
Frederick Hartman

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**QUANTIFYING THE BENEFIT OF FACILITY-BASED MIXED REALITY
TRAINING IN SUPPORT OF THE FITE JCTD BUSINESS CASE ANALYSIS**

Chez Yee Ang
Civilian, Defense Science and Technology Agency, Singapore
B.Eng (Hons), Nanyang Technological University, 1997

Submitted in partial fulfillment of the
requirements for the degree of

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from the

**NAVAL POSTGRADUATE SCHOOL
December 2009**

Author: Chez Yee Ang

Approved by: Dr. Daniel A. Nussbaum
Thesis Advisor

Mr. Frederick Hartman
Second Reader

Dr. Robert Dell
Chairman, Department of Operations Research

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ABSTRACT

The nature of modern ground warfare has become increasingly complex and will continue to do so. Future conflicts require participants to have improved decision-making skills in an environment where tactical decisions have strategic implications. Today, small-unit combat trainers lack the means to create training conditions that reinforce such decision-making skills. On top of traditional training-enabler requirements, these training resources must provide an immersive training environment that is culturally realistic and interactive.

The Future Immersive Training Environment (FITE) was proposed as a Joint Capability Technology Demonstration (JCTD) in October 2008 in response to this need. It is divided into two parts:

- Spiral 1 – Individually-worn Virtual Reality
- Spiral 2 – Facility-based Mixed Reality & Individually-worn Augmented Reality.

The FITE JCTD is a two-year USJFCOM-led JCTD designed to enhance immersive training technologies by demonstrating, assessing and transitioning such capabilities into service programs of record.

Unfortunately it is difficult to build a good business case for a new training capability because there is no existing system against which to compare. This thesis uses learning curve theory to quantify the benefit of training soldiers in an immersive, mixed-reality environment in terms of reducing combat fatalities. When compared against the estimated investment over the system life cycle, the results show attractive returns over a broad range of input parameters. The results of this thesis could provide input to the Future Immersive Training Environment (FITE) Joint Capability Technology Demonstration (JCTD) Business Case Analysis (BCA).

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LIST OF ACRONYMS AND ABBREVIATIONS

AAR	After Action Review
BCA	Business Case Analysis
CA-CTF	Combined Arms Collective Training Center
DF	Discount Factor
DSCCTT	Dismounted Soldier Close Combat Tactical Trainer
FAA	Federal Aviation Administration
FITE	Future Immersive Training Environment
IIT	Infantry Immersion Trainer
I-MTS	Integrated Military Operations on Urban Terrain Training System
ISR	Intelligence, Surveillance and Reconnaissance
JCTD	Joint Capability Technology Demonstration
JOE	Joint Operating Environment
MOUT	Military Operations on Urban Terrain
NPV	Net Present Value
O&S	Operations and Support
OPFOR	Opposing Forces
PEO STRI	Program Executive Office for Simulation, Training & Instrumentation
ROI	Return on Investment
SH	Shoot House
UAC	Urban Assault Course

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EXECUTIVE SUMMARY

The nature of modern ground warfare has become increasingly complex and will continue to do so. Future conflicts require participants to have improved decision-making skills in an environment where tactical decisions have strategic implications. Today, small-unit combat trainers lack the means to create training conditions that reinforce such decision-making skills. On top of traditional training-enabler requirements, these training resources must provide an immersive training environment that is culturally realistic and interactive [14].

The Future Immersive Training Environment (FITE) was proposed as a Joint Capability Technology Demonstration (JCTD) in October 2008 in response to this need. It is divided into 2 parts:

- Spiral 1 – Individually-worn Virtual Reality
- Spiral 2 – Facility-based Mixed Reality & Individually-worn Augmented Reality.

Unfortunately it is difficult to build a business case for a new training capability because there is no existing system against which to compare. This thesis uses learning curve theory to quantify the benefit of training soldiers in an immersive, mixed-reality environment in terms of reducing combat fatalities. If soldiers could be trained, prior to deployment, in an environment that closely replicates the conditions and scenarios found in the area of operations, such that the initial X months spent struggling to adapt to the operating environment could be done under less threatening but equally stressful circumstances, overall fatalities could be reduced. The number of combat fatalities thus avoided in a twelve-month tour of duty cycle would be:

$$CT_{12,0} - CT_{12,X} = A(12)^{b+1} - A\left[(12+X)^{b+1} - X^{b+1}\right]$$

where,

A – average fatality at month 1

N – number of months in theater

2^b – slope of the learning curve

$CT_{N,X}$ – total fatalities in N months

From regression analysis of Vietnam War combat fatality data, the number of U.S. Army and Marines combat fatalities relative to the amount of time spent in-theater was found to follow a 69 % learning curve. This learning curve is then applied to Operation Iraqi Freedom and Operation Enduring Freedom combat fatality data from the period 2001 to 2008 to make up the baseline scenario. The parameters for the baseline scenario are listed in Table 1.

Parameters	Value
Fatalities Avoided per year [pax]	164
Economic Value per Fatality Avoided [FY08\$K]	3,647
Economic Value of Fatalities Avoided [FY08\$K]	91,175
Total Number of Training Sites	5
Total Investment Period [year]	10
Total R&D [FY08\$K]	71,414
Total Procurement [FY08\$K]	189,515
O&S per year [FY08\$K]	12,700

Table 1. Parameters for baseline scenario.

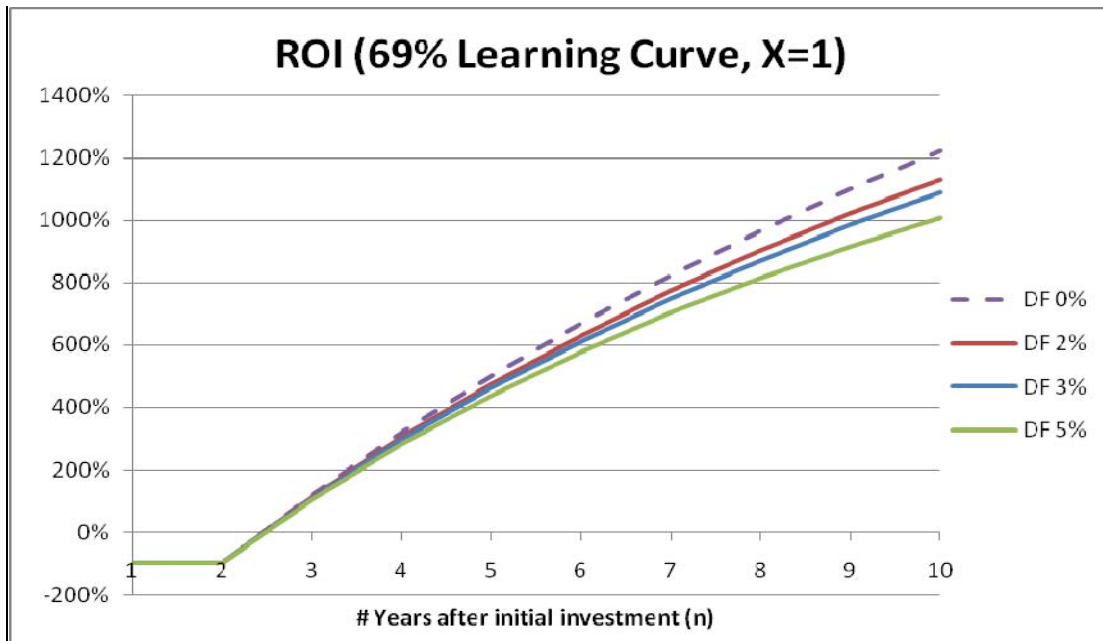


Figure 1. Baseline scenario over system lifetime

Figure 1 shows that if the FITE Facility-based Mixed Reality training is effective enough to substitute for one month's ($X = 1$) equivalent of "combat experience," the investment would break even between two to three years, and the Return on Investment (ROI) over the system lifetime would be between 1000–1200 % depending on the discount factor (DF) used. Sensitivity analysis also revealed that the investment would still break even, for less than 3% DF, over its lifetime if the real learning curve in terms of combat fatalities is as flat as 95 %. This calculation assumes that R&D and procurement takes up two years and the systems are in use for eight years.

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I. INTRODUCTION

A. PURPOSE OF THE STUDY

This thesis proposes a means to quantify the operational benefit accrued from investing in the Facility-based Mixed Reality training system under development in a Joint Capability Technology Demonstration (JCTD) called the Future Immersive Training Environment (FITE). The analysis in this thesis is intended as an input to the eventual FITE JCTD Business Case Analysis (BCA).

With the end of the Cold War, the likelihood of conventional warfare has diminished and future ground conflicts are increasingly likely to occur within populated urbanized areas between asymmetric forces. Soldiers today are not only expected to “fight the war,” they are also expected to “win the peace,” These seemingly conflicting demands may require decision-making skills which soldiers today do not yet possess. Coupled with ever more extensive media coverage on the modern battlefield, these improved decision-making skills are becoming more crucial where tactical actions have strategic implications. As a result of these complexities and increased small-unit leadership demands, small units need improved training systems that create and reinforce complex situation awareness and decision-making skills [14].

One way to achieve this is a fully immersive, culturally realistic training environment where trainees are subjected to a wide variety of decision-making stimuli. In order to have a fully immersive environment, elements of the visual, audio, tactile, olfactory and environmental conditions of the battlefield need to be created. For resource-effective training, high-fidelity virtual entities are needed [14].

An investment in such cutting-edge training technology requires substantial resources. Justification for such an investment is pretty straightforward if it is to replace an existing system or when there are other competitive alternatives with which to compare. By comparing the expected resource savings versus replacing the existing system, or by finding the most cost effective alternative, one can make a business case as to whether to proceed with the investment. In the case of FITE’s Facility-based Mixed

Reality, however, the training system addresses a new operational requirement for which there is no status quo or equivalent alternative. Hence, there is a need to find a way to quantify improvements in operational outcomes arising from this investment.

B. IMMERSIVE TRAINING ENVIRONMENT

Virtual environments have two essential characteristics that provide justification for their employment in training applications. First, virtual environments are immersive, that is, they substitute synthetically generated sensory input for sensory data from the real world. Second, virtual environments are interactive, that is, when a user provides input to the system, the results of that input are almost immediately apparent. These two characteristics, along with content, determine the quality of the user's experience in such a training environment [12].

1. Mixed Reality and Augmented Reality

Milgram *et al.* proposed the relationship between Reality and Virtuality as a continuum, with the real physical environment at one end and the fully synthetic one at the other [13]. Mixed Reality applications fall between these extremes. Therefore, FITE's Facility-based Mixed Reality implementation does not fit into the taxonomy of Mixed Reality as defined by Milgram *et al.* Instead, it is a physical environment where virtual entities, together with audio, kinetic and olfactory effects, combine to give a "close-enough" substitute for the actual operating environment.

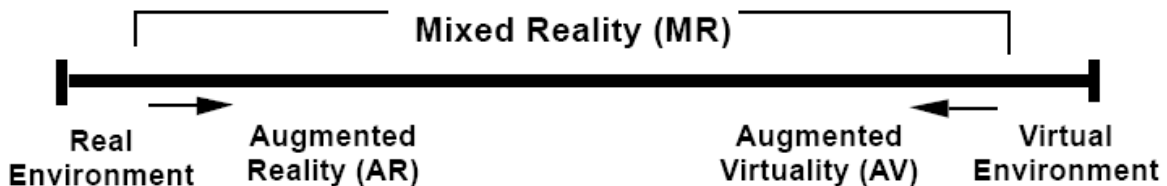


Figure 2. Reality – Virtuality Continuum (From [13]).

C. PROBLEM STATEMENT

The aim of this thesis is to conduct a systematic evaluation of the cost benefits of the FITE Facility-based Mixed Reality using the learning curve theory. The cost evaluation shall be based on the life-cycle costs (R&D, procurement, O&S) of a brand-new FITE Facility-based Mixed Reality capability. The analysis in this document will use the ongoing Operation Iraqi Freedom and Operation Enduring Freedom, in Iraq and Afghanistan respectively, as the reference operational environments.

D. FITE DESIRED CAPABILITIES

Four primary Desired Capabilities [14] of FITE have been identified by the operational user community:

- an integrated, interoperable, immersive training environment
- trainee feedback
- joint enablers
- collective after action review (AAR)

Detailed measures of performance, measures of effectiveness, thresholds and objectives are listed in Appendix A.

1. Integrated, Interoperable, Immersive Training Environment

The integrated, interoperable, immersive training environment will replicate elements of the visual, audio, tactile, olfactory and environmental conditions of the battlefield to improve cognitive decision-making skills. The environment will provide culturally realistic and reactive synthetic entities that allow realistic interaction within the Joint Operating Environment (JOE) (i.e., trainees, higher headquarters and adjacent units, supporting arms, civilians and opposing forces (OPFOR)). Team members will be able to exercise complex kinetic and non-kinetic and higher order decision making under stressful conditions. The training environment will facilitate repeatable and rapidly reconfigurable scenarios [14].



Figure 3. Photos of FITE Facility-based Mixed Reality (From Mr. Rick Dunlap, APM, PEO STRI)

2. Trainee Feedback

Trainees will experience an instantaneous and in-stride response to their interactions with the training environment. Virtual entities, kinetic and non-kinetic effects will be responsive and physically accurate. This capability aims to encourage positive habit transfer as a result of training [14].

3. Joint Enablers

Joint enablers will allow the trainee to request, control and coordinate supporting arms and Intelligence, Surveillance, and Reconnaissance (ISR) assets as appropriate within the training scenario [14].

4. After Action Review (AAR)

The AAR capability serves to capture lessons learned and ensure the best use of training resources. This capability provides for record and playback of each entity's movements, orientation, and communications during the training session. A user-friendly interface will facilitate collective AARs, real-time exercise monitoring and rapid trend analysis [14].

E. RESEARCH METHODOLOGY

Since this report is intended as an input to FITE JCTD BCA, it will adopt a similar approach. The Defense Acquisition University describes a generic BCA methodology as a four-phase process [4]. The phases are:

- Definition
- Collection of data
- Analysis
- Presentation of results

1. Definition

In the Definition phase, the scope, assumptions, constraints and alternatives to be investigated are identified. The Definition phase sets the boundaries and guides the analysts in delivering a credible product. The scope of this thesis is limited to the Facility-based Mixed-Reality implementation in the FITE JCTD.

2. Collection of Data

In this phase, the types and sources of data required and means of collection are identified. After data is collected, it needs to be normalized across time and substance so

that fair comparisons can be made between alternatives. One common way to normalize cost data would be to apply inflation indices to return the data to some constant base year. Models are developed so that data collected can be stored, categorized, and their integrity preserved [4].

3. Analysis

In the Analysis phase, the business case for each alternative is developed and then compared with the other alternatives as well as the baseline to determine the option with the best cost-benefit combination. Sensitivity analysis is performed to determine variations in outcome due to changes in the validity of assumptions made. In some cases, risk analysis is performed to determine, if any, the likelihood of unfavorable events that may impact each alternative.

4. Presentation of Results

At the conclusion, courses of action are recommended to the decision maker together with the supporting analysis. Appropriate charts, tables and quantitative data are presented to help convey the process of analysis and to highlight any unexpected results.

F. ASSUMPTIONS AND LIMITATIONS

The extent of the analysis is heavily dependent upon the data available. In order to scope the research effort within the academic time frame available, the following simplifying assumptions have been made:

- A conservative approach is adopted, i.e., where a choice is to be made between a higher and lower cost due to ambiguity of data, the higher cost is used.
- Where essential information is not explicitly available, reasonable estimates or inferences from suitably analogous sources are made.
- Where O&S cost data are unavailable, they are assumed to be 10 % of procurement costs.
- Disposal costs of this system are assumed to be negligible with respect to the other components of the Life Cycle Cost.
- All cost data are normalized to a base year of FY08.

- Indirect costs associated with the Total Cost of Ownership (e.g., costs of additional training time) are not taken into account in this analysis. In other words, investment cost only takes into account the costs of developing, procuring and operating the system during its lifetime.

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II. BACKGROUND

A. ANALYSIS OF ALTERNATIVES

There are several systems and products that are targeted at training infantry squads in urban operations. Some, like ExpeditionDI® by Quantum3D Inc., VIRTSIM™ System by Motion Reality Force Simulation Inc., and Dismounted Soldier Close Combat Tactical Trainer (DSCCTT) utilize fully virtual environments and entities to achieve their training objectives. Others, like the Integrated Military Operations on Urban Terrain (MOUT) Training System (I-MTS) are sprawling, highly-instrumented training facilities designed to train battle drills, conduct battalion and brigade-level maneuvers and live-fire exercises. Some of these systems are briefly introduced and compared with the FITE Facility-based Mixed Reality system in the following paragraphs.

1. Motion Reality Force Simulation VIRTSIM™ System

The VIRTSIM™ system by Motion Reality Force Simulation Inc. is an individually-worn immersive virtual training environment that can accommodate up to twelve trainees and one trainer in visually accurate combat scenarios. Trainees are completely untethered and able to fire and maneuver as they would in live combat. Each training facility can set up in any large indoor space using lightweight aluminum truss and customized, reusable shipping crates without specialized building requirements. VIRTSIM™ systems can be networked together to allow groups at different facilities to train in the same virtual environment in real-time via an Internet connection [7].

VIRTSIM™ technology offers high capacity training that simultaneously stresses a full squad of twelve trainees physically and cognitively in real time, through customizable 3D scenarios and interactive AI characters that engage trainees. Kinetic weapon effects and encounters with virtual barriers such as walls and obstacles are simulated with low-level vibrations. Knowledge retention is reinforced with After Action Review (AAR) that supports playback from any angle or character's perspective [7].

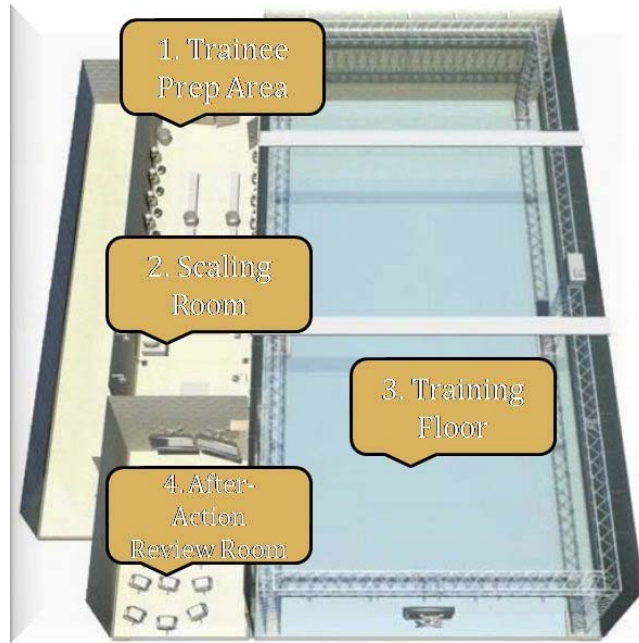


Figure 4. VIRTSIM™-HT (High-Throughput) System Layout (From [9])

2. Quantum3D ExpeditionDI®

ExpeditionDI® by Quantum3D is an individually-worn, immersive virtual reality training system. It is an untethered system that contains features similar to VIRTSIM™ but does not require a fixed infrastructure setup, allowing training to be conducted anywhere. The ExpeditionDI® synthetic environment replicates visual and audio elements of the battlefield, but not the tactile, olfactory and ambient effects. It claims to provide interactive AI characters that engage trainees but there is no kinetic feedback to simulate the physical sensations of gunshots or virtual barriers. The system allows for coordinated squad-level training by accurately reflecting the team's actions across the head-mounted displays of all other participants, and includes instructor stations with facilities for after action review (AAR). This AAR capability is purportedly able to replay the training session from any angle or character's perspective.



Figure 5. Quantum3D ExpeditionDI® System Components (From [8]).

3. Integrated MOUT Training System (I-MTS)

The I-MTS consists of three training facilities/systems: The Urban Assault Course (UAC), Shoot House (SH) and Combined Arms Collective Training Facility (CA-CTF). These systems are designed to provide the individual soldier through Battalion-level homestation urban-operations training. These training facilities allow units to train warfighters for building entry and room-clearing techniques under live and blank-fire conditions. By providing state-of-the-art urban training facilities capable of training today's soldiers in a realistic urban environment, the Army ensures that soldiers have the highest level of urban training short of combat. Lessons are learned on the training ground and not in battle. These systems monitor and control the training exercise, process, display and analyze collected exercise data, prepare and present standardized training performance feedback, and archive training performance information for external use [15].



Figure 6. View of I-MTS (From [15])

4. Infantry Immersion Trainer (IIT)

The IIT is a live and virtual training facility for small unit urban operations. It arose out of a Joint Capability Technology Demonstration (JCTD) and has been in use since 2007 [21]. The IIT provides a physical environment and infrastructure, with a data and communications network to provide small unit training capability with immersive elements. Some technology components developed under the IIT JCTD, like the Synthetic Environment, Weapons Fire and Effects Detection System, 3D Tracking and Live/Synthetic Environment Integration, form the basis on which the FITE Facility-based Mixed Reality will be built [22]. Eventually, an operational mixed-reality training facility will consist of components from both FITE and IIT. Hence, for the purpose of this analysis, the cost of the IIT is considered part of the Life Cycle Cost of the FITE Facility-based Mixed Reality.

5. Comparing FITE Facility-based Mixed Reality with Alternatives

A comparison between the above-mentioned systems with FITE Desired Capability metrics (in Appendix A) are listed in the following pages. From Tables 2, 3 & 4, it is clear that none of the alternatives completely meets the Desired Capabilities of FITE. Therefore, none of them are suitable analogous systems to be used to quantify the benefits of Facility-based Mixed Reality.

	Replicates elements of the visual, audio, tactile, olfactory, effects and conditions of the battlefield across the full spectrum of operations in order to improve cognitive skills			
Attribute/ Condition	Visual: Natural Field of View (FOV), Natural Field of Regard (FOR), Resolution, Natural method for changing FOV	Audio: Hear sounds from all directions, and properly attenuated	Tactile: Feel operational environment effects	Olfactory: Smell operational environment effects
FITE (Facility-based Mixed Reality) / IIT	75% report that the environment is sufficient to train the tasks and superior to live training	75% report that the environment is sufficient to train the tasks and superior to live training	75% report that the environment is sufficient to train the tasks and superior to live training	75% report that the environment is sufficient to train the tasks and superior to live training
Home Station MOUT facility	Yes	limited	limited	limited
VIRTSIM™	Yes	yes	no	no
ExpeditionDI®	Yes	yes	no	no

Table 2. Comparison of Alternatives Against FITE Desired Capability: Integrated, Interoperable, Immersive Training Environment Part I (After [14])

	Team members exercise close combat tasks in a realistic fully immersive training environment that creates and reinforces complex (tactical and human dimension) decision-making skills		Provides culturally realistic, reactive, dynamic, synthetic entities that allow realistic interaction with team members, higher headquarters, adjacent units, supporting arms, civilians and OPFOR	Repeatable and rapidly reconfigurable scenarios and environment to include home station	Real-time, physically accurate representation of ballistic effects
Attribute/ Condition	Team members exercise close combat in simulated environment	Simulated environment induces sufficient stress in the trainee	Virtual Environment portrays individuals with sufficient fidelity to allow trainee to exercise culturally realistic training	Unit Leader can rapidly reconfigure scenarios and physical settings	Virtual characters respond realistically to being hit by small arms fire
FITE (Facility-based Mixed Reality) / IIT	75% report that the environment is sufficient to train the tasks and superior to live training	75% report that the environment is sufficient to train the tasks and superior to live training	75% report that the environment is sufficient to train the tasks and superior to live training	100% repeatable and near real time reconfigurable	75% report that the environment is sufficient to train the tasks and superior to live training
Home Station MOUT facility	No	no	no	yes	no
VIRTSIM™	Yes	yes	yes	yes	yes
ExpeditionDI®	Yes	yes	yes	yes	no

Table 3. Comparison of Alternatives Against FITE Desired Capability: Integrated, Interoperable, Immersive Training Environment Part II (After [14])

	Provide feedback instantaneously and in-stride	Replicate kinetic and non-kinetic interactions for trainee(s)	Trainee request, control, and coordinate supporting arms and Intelligence, Surveillance, and Reconnaissance (ISR) within the training scenario	Record and playback each entity's movements, orientation, and communications	Provide rapid trend analysis
Attribute/Condition	Real time, realistic portrayal of battlespace and entities.	Realistic portrayal of kinetic and non-kinetic battlespace.	Realistic portrayal of requesting joint enablers / combined arms integration	Accurate and automated playback	Timely analysis of performance trends
FITE (Facility-based Mixed Reality) / IIT	At least 50% of trainees actions are able to be critiqued immediately by trainer (as appropriate)	75% of engagements are reported properly	Requests for fire are submitted, answered, and coordinated	At least 50% of kinetic, verbal, and gestural interactions are recorded, analyzed, and available for review upon completion of training	System will record all exercises and allow for trend analysis
Home Station MOUT Facility	Limited to observation by trainer	Observation of SESAMS/UTM marks if used / Not possible	Supporting arms requests for fire are not represented	Entities movement, orientation, and communications is currently not captured.	no
VIRTSIM™	yes	Yes	no	yes	yes
ExpeditionDI®	yes	No	no	yes	no

Table 4. Comparison of Alternatives Against FITE Desired Capabilities: Trainee Feedback, Joint Enablers and AAR (After [14])

B. JOINT CAPABILITY TECHNOLOGY DEMONSTRATION

The primary goal of the JCTD Program is to demonstrate, operationally assess, rapidly deploy, and transition capability solutions and innovative concepts to address the joint coalition and interagency operational gaps and shortfalls [2]. The current JCTD Program has its roots from the Advanced Concepts Technology Demonstration Program (ACTD). It is managed by the Office of the Deputy Undersecretary of Defense, Advanced Systems & Concepts, in concert with the Joint Staff. A JCTD must set out to meet the nearer-term needs of the warfighter and deliver a product that provides for evaluation and refinement [3].

Advanced technology identified for accelerated development and operational evaluation under a JCTD must be available within one year of project initiation, and the JCTD must be completed by the end of the third year [1].

1. FITE Facility-based Mixed Reality Core Technologies

Technology	Providers
Game Engine components	DARPA Real World and VBS-2
Avatar Reaction and Control	Lockheed Martin
Individual Position & Weapon Tracking	InterSense, PhaseSpace, Sarnoff
Scenario Generation System	Lockheed Martin, Bohemia
Exercise / Operator Control	Lockheed Martin
Language Recognition & Cultural System	Tactical Language Training System/ALTS
Data Collection and After Action Review	Lockheed Martin
Spatialized Sound System	Lockheed Martin, Bohemia
Olfactory (smell) Generator	ScentAir

Table 5. Technologies relevant to Facility-based Mixed Reality (After [20])

FITE leverages on several existing technologies for its Facility-based Mixed Reality implementation. The objective is to further develop and successfully integrate all these component technologies and transit them into a new Program of Record.

C. BUSINESS CASE ANALYSIS

A Business Case Analysis (BCA) is a financial tool used to support planning and decision making. It seeks to inform decision makers about the scope, risk and likely financial consequences of each alternative, based on available data, and help them arrive at the best course of action. The BCA is an iterative process that is updated as the business and mission environment changes. It assesses each alternative and weighs total cost against total benefits to arrive at the optimum solution. The BCA process goes beyond cost/benefit or traditional economic analysis by documenting how each alternative fulfils the strategic objectives of the program, how it complies with product support performance measures, and the resulting impact on stakeholders. The BCA identifies which alternative support options provide optimum mission performance given cost and other constraints, including qualitative or subjective factors [4].

Depending on the assumptions and arbitrary judgements, two independently-conducted BCAs that evaluate the same scenario can produce quite different results. Therefore the traceability and transparency of the results is as important as the results themselves [5].

As every BCA differs in the objectives, assumptions, constraints, and risk and operation scenario, it is natural to expect that each BCA is customized for a particular case within a specific operating environment. A typical BCA consists of the following elements [6]:

- Determine objectives
- Specify assumptions and constraints
- Identify possible alternatives, including status quo
- Estimate cost and benefits of every alternative
- Perform sensitivity analysis and risk analysis
- Derive conclusions and make suitable recommendations

III. QUANTIFYING THE BENEFIT

A. LEARNING CURVE THEORY

In today's asymmetric warfare, the exact parameters of mission success may be varied and hard to quantify. However, at the small-unit level, a reduction in casualty levels while performing the same type and number of missions is always a good proxy for mission success.

The dominant factor in learning curve theory is based on the direct observation that as a task is accomplished several times, it can be completed in shorter periods of time. This idea was first suggested in 1936 by T. P. Wright in his article "Factors affecting the cost of airplanes" where he proposed the cumulative average learning curve theory [24]. It states that as the quantity of production is doubled, the average cost of the total quantity produced is equal to the average cost before doubling, multiplied by the slope of the learning curve.

If the same concept is extended to low-intensity conflict missions of a somewhat repetitive nature, like foot patrols in a peacekeeping operation, a learning curve could be used to represent the impact of combat experience on improvements in casualty rates over the duration in theater.

1. Combat Fatalities and Combat Experience

Studies have shown that a majority of pilot casualties occur during a pilot's first ten combat missions. Therefore, if a new pilot could log his first ten "combat missions" in a controlled environment, he would go into combat having "survived" his most vulnerable period. The *Red Flag* series of air combat exercises was created out of this idea [25]. If such "learning effects" are also evident in land warfare, it could be used as a means to quantify the benefit of realistic, immersive small-unit training.

From the compilation of Vietnam War battle and non-battle casualty statistics by the U.S. Army Administration Center [10], it was found that the longer a soldier stayed alive after arriving in theatre, the better his chances were for survival, presumably as a

result of experience. For the U.S. Army and Marines, nearly twice as many troops died during the first three months of their tour than in the next three months and the numbers decreased steadily as their tour progressed. The number of Army and Marine combat fatalities is plotted against the soldier's length of stay in theater in Figure 7 [10].

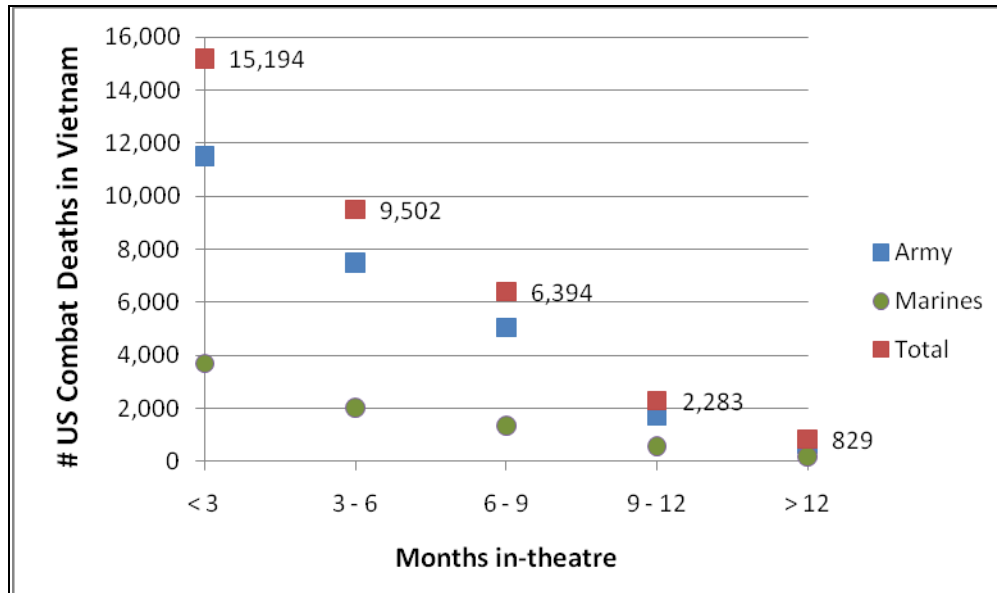


Figure 7. Relationship between U.S. Combat Fatalities in Vietnam 1965–1972 and the Casualty's Length of Time In Theater

2. Applying Learning Theory to Vietnam War Combat Fatalities

Using a cumulative average learning model, the average fatality rate is given by:

$$Y_N = AN^b$$

where,

Y_N – cumulative average fatality at month N

A – average fatality at month one

N – number of months in theater

2^b – slope of the learning curve

And the total fatality in N months is given by:

$$\begin{aligned} CT_N &= AN^b \square N \\ &= AN^{b+1} \end{aligned}$$

3. Regression Analysis

The length of tours of duty in Vietnam was twelve months with possible extensions of a further six months. Assuming an eighteen-month tour of duty, a linear regression with natural log transformation was performed on combined U.S. Army and Marines combat fatalities in Vietnam to estimate parameters of the cumulative average learning curve. The transformed linear model is as follows:

$$\begin{aligned} Y_N &= AN^b \\ \ln Y_N &= \ln A + b \ln N \end{aligned}$$

The regression statistics in Table 6 reveal a good fit for the Vietnam War casualty data to the learning curve model. The p-value of the F-statistic is 0.009, which means that

there is strong evidence of learning (i.e., $b \neq 0$). The Coefficient of Determination (R^2) shows that the model accounts for more than 92 % of the variability in the data.

<i>Regression Statistics</i>	
Coefficient ($\ln A$)	9.204
Coefficient (b)	-0.529
F-statistic (p-Value)	0.009
Coefficient of Determination (R^2)	0.927
Standard Error	0.118
Observations	5

Table 6. Summary of Regression on Vietnam War Combat Fatalities Data

The model suggests a 69 % learning curve with a regression standard error of 0.118 (i.e., $2^{-0.529} \approx 0.69$ is the ratio of the average fatalities in N months to the average fatalities in $\frac{N}{2}$ months). Details of the linear regression are listed in Appendix B.

4. Learning Theory in Recent Combat Fatality Data

In 2004, Col. Larry Saul, then Director of Center for Army Lessons Learned, was quoted in a *Defense News* article: "...I see many disturbing similarities between what I experienced as a 19-year-old infantryman and what our 19-year-old infantrymen are experiencing today in Iraq - particularly with mines and booby traps" [23]. Therefore, it is likely that a learning curve may be applicable in today's battlefields. Combat fatalities from Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) [11] are listed in Table 7.

Total OIF Army & USMC Combat Fatalities (Mar 03 - Oct 09):	3,372
Average OIF Combat Fatalities per year:	519
Total OEF Army & USMC Combat Fatalities (Oct 01 - Oct 09):	592
Average Combat Fatalities per year:	74
Combined OEF Average Combat Fatalities per year	593

Table 7. Combat Fatalities from Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF)

Assuming that the same 69 % learning curve from the Vietnam War applies in OIF and OEF, and tours of duty were at least twelve months long, average combat fatality after the first month is:

$$CT_N = AN^{b+1}$$

$$A = \frac{593}{(12)^{b+1}}$$

5. Accelerating the Learning Curve

Linton and Walsh argued theoretically that when applied to manufacturing processes using emerging process technologies, improvements in productivity due to advances in technology have the effect of shifting the learning curve [24]. Along a similar vein, if soldiers could be trained prior to deployment in an environment that closely replicates the conditions and scenarios found in the area of operations, such that the equivalent of the initial X months spent struggling to adapt in-theater could be done under less-threatening but equally stressful circumstances, they would have effectively “survived” this vulnerable period and gained “combat experience”. The resultant learning curve equation (with additional FITE training) then becomes:

$$Y_{N,X} = A(N + X)^b$$

Total fatalities in N months (with additional FITE training) are given by:

$$CT_{N,X} = A(N + X)^{b+1} - AX^{b+1}$$

Therefore, the number of fatalities avoided over a 12-month tour of duty cycle due to an X -month shift in learning curve is:

$$CT_{12,0} - CT_{12,X} = A(12)^{b+1} - A[(12 + X)^{b+1} - X^{b+1}]$$

As an illustration, the expected number of fatalities¹ avoided, for values of $X = 0.5, 1$ and 2 over learning curves of various slopes, is listed in Table 8. As the learning curve becomes flatter (higher percentage), the impact of better training on combat fatalities becomes smaller.

¹ Rounded to nearest integer.

Learning Curve	b	A	X=0.5	X=1	X=2
			$CT_{12,0}-CT_{12,0.5}$	$CT_{12,0}-CT_{12,1}$	$CT_{12,0}-CT_{12,2}$
100%	0.000	49.42	0	0	0
97%	-0.044	55.12	5	8	13
95%	-0.074	59.39	8	14	22
93%	-0.105	64.10	12	20	31
85%	-0.234	88.49	33	51	76
78%	-0.322	109.97	61	89	126
73%	-0.415	138.60	91	126	171
69%	-0.535	186.89	124	164	214

Table 8. Combat Fatalities Avoided

B. EVALUATING THE INVESTMENT

All cost data used in this analysis were obtained either from the FITE JCTD Management and Transition Plan [14], the IIT Irregular Warfare Conference briefing slides [22] or through telephone interviews with the program manager. The financial expediency of FITE Facility-based Mixed Reality is evaluated on the principles of Net Present Value (NPV) and Return on Investment (ROI).

1. Life Cycle Cost

The Defense Acquisition University defines Life Cycle Cost as the total cost to the government over the lifetime of a defense acquisition program [16]. The life cycle cost of a defense acquisition program typically consists of the following components [17]

- Research and Development
- Procurement
- Operations and Support (O&S)
- Disposal

For the purpose of this analysis, the disposal costs are assumed to be negligible with respect to the other three cost components over the lifetime of the system.

	FITE Facility-based Mixed Reality / \$K	IIT / \$K	Total for Facility-based Mixed Reality + IIT / \$K
R&D	24,351	47,063	71,414
Procurement (per site)	4,000	33,903	37,903
O&S (per yr)	400	2,140	2,540

Table 9. Life Cycle Cost Components for FITE Facility-based Mixed Reality (in FY08\$K)

The NPV of the investment is given by:

$$NPV = \sum_{t=0}^n \frac{CF_t}{(1+k)^t}$$

where

n – time horizon of the cash flow

k – discount factor

CF_t – net cash flow in time period *t*

2. Economic Value of Avoided Fatality

The Federal Aviation Administration (FAA) defines the economic value of each avoided fatality in an airline accident as three million dollars [18] in FY01\$. Given that soldiers are trained and equipped at great expense, each combat fatality increases demand on recruitment, training and reinforcements along the manpower supply chain. Therefore, the economic value defined by the FAA serves as a lower bound to the economic value of a combat fatality avoided. Adjusted for inflation, the value would be \$3,647 in FY08\$K [19].

3. Return on Investment (ROI)

The Return on Investment (ROI) is a commonly used financial metric for determining whether an investment is worth undertaking. This is done by comparing the

potential income generated against total investment. Though it does not take into account risk, ROIs of different alternatives can be compared against each other or the time value of money to determine whether the investment is worth making. The ROI formula for FITE Facility-based Mixed Reality is given as:

$$ROI = \frac{Income}{Investment} = \frac{Value\ of\ Avoided\ Fatalities}{NPV\ of\ Investment}$$

C. BASELINE SCENARIO

The following assumptions are made for the baseline scenario:

- R&D is done within one year.
- The equipping scale is five sites, procurement starts immediately after completion of R&D and the system is operational within one year.
- O&S costs are incurred from the third to the tenth years.
- The system has an eight-year life cycle and the U.S military continues to be involved in conflicts of a similar scale to OIF and OEF throughout the entire period.
- Tours of duty are twelve months long. This means that a new batch of soldiers is deployed to the theater of operations every year and encounters the same learning curve.
- The training capacity of the FITE Facility-based Mixed Reality is at least equal to the current IIT training capacity.
- The length of time spent in theater is proportional to the number of combat missions undertaken.
- FITE Facility-based Mixed Reality translates to a one-month in-theater experience (i.e., $X=1$).
- Soldiers today face the same learning curve of 69 % ($b = -0.529$) from regression analysis of the Vietnam War casualty data.
- Discount factors of 0%, 2%, 3% and 5%.

Parameters	Value
Fatalities Avoided per year (from Table 8.) [pax]	164
Economic Value per Fatality Avoided [FY08\$K]	3,647
Economic Value of Fatalities Avoided [FY08\$K]	91,175
Total Number of Training Sites	5
Total Investment Period [years]	10
Total R&D [FY08\$K]	71,414
Total Procurement [FY08\$K]	189,515
O&S per year [FY08\$K]	12,700

Table 10. Parameters for baseline scenario

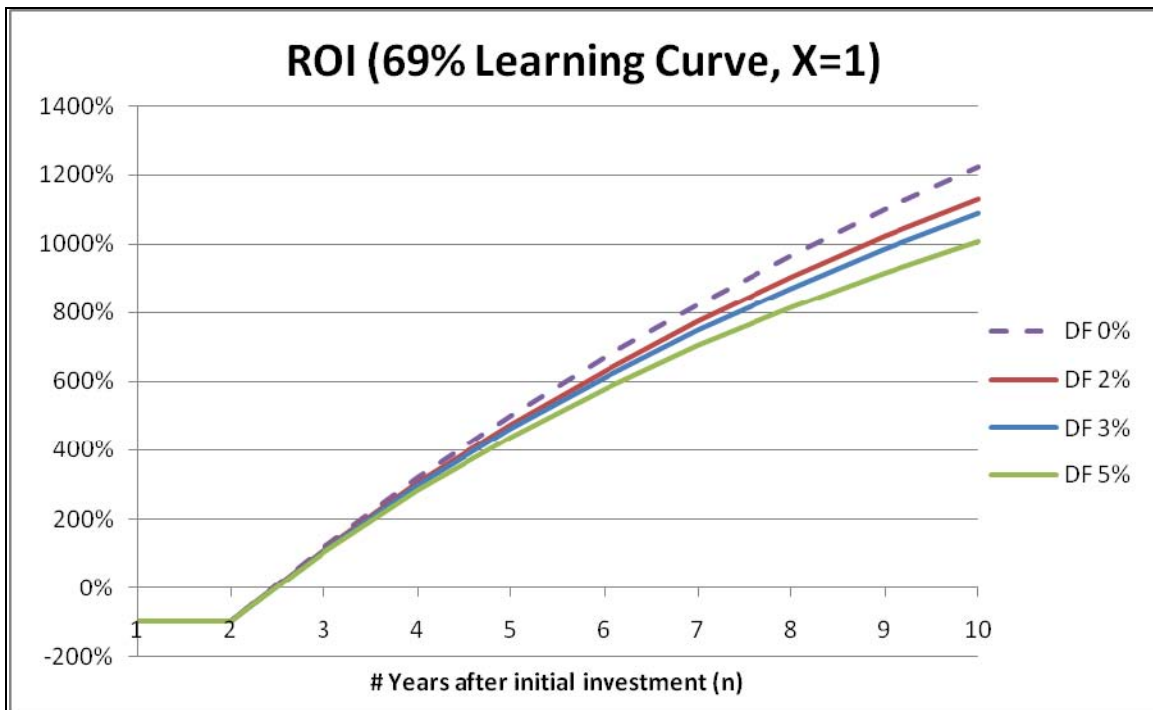


Figure 8. Baseline scenario ROI over system lifetime

With a learning curve of 69%, a one-month improvement in combat experience could reduce fatalities by an estimated 28%. The ROI is calculated for the first ten years of a system's lifetime and is shown in Figure 8. The graph shows that the investment in FITE Facility-based Mixed Reality breaks even between the second and third year after the initial investment, with any reasonable discount factor, and an ROI of between 1000–1200% over the investment period.

D. SENSITIVITY ANALYSIS

1. Slope of the Learning Curve

Most of the soldiers who fought in the Vietnam War were draftees. In contrast, today's military is a professional, all-volunteer force. New personal equipment like body armor, Kevlar helmets and ballistic goggles means soldiers today are better protected, while training facilities like I-MTS turn out soldiers better trained in basic soldiering skills like marksmanship, room clearing and other combat drills. Therefore, it is more than likely that today's soldiers are better prepared physically and mentally when they arrive in theater compared to those during the Vietnam War. Being better prepared could help soldiers adapt more quickly to actual battlefield conditions and result in a flatter learning curve. The following paragraphs illustrate the sensitivity of the result when the learning curve is varied from 73% to 95%.

a. 73% Learning Curve

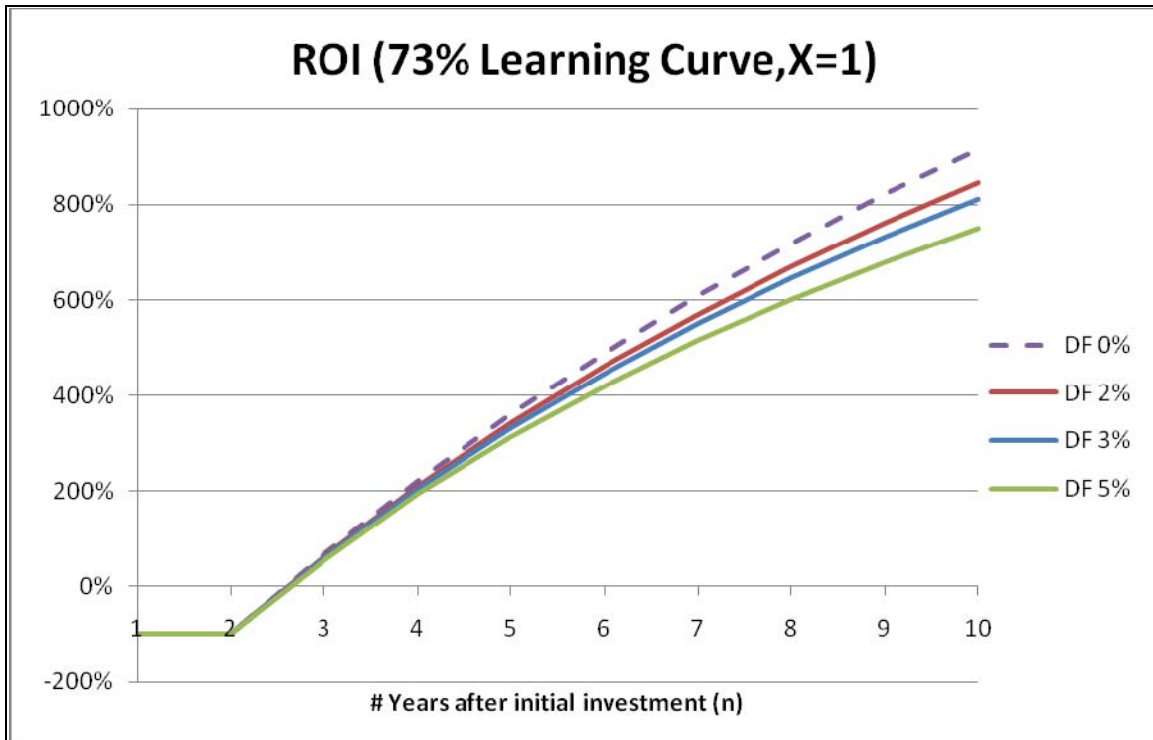


Figure 9. ROI with 73% learning curve & X=1.

If the standard error for b is taken into account, the Vietnam War learning curve could be as flat as 73% (i.e., $2^{-0.535+0.086} \approx 0.73$). With a 73% learning curve, the investment still breaks even between the second and third year of investment with an ROI of 750–900% over ten years, depending on the discount factor used.

b. 78% Learning Curve

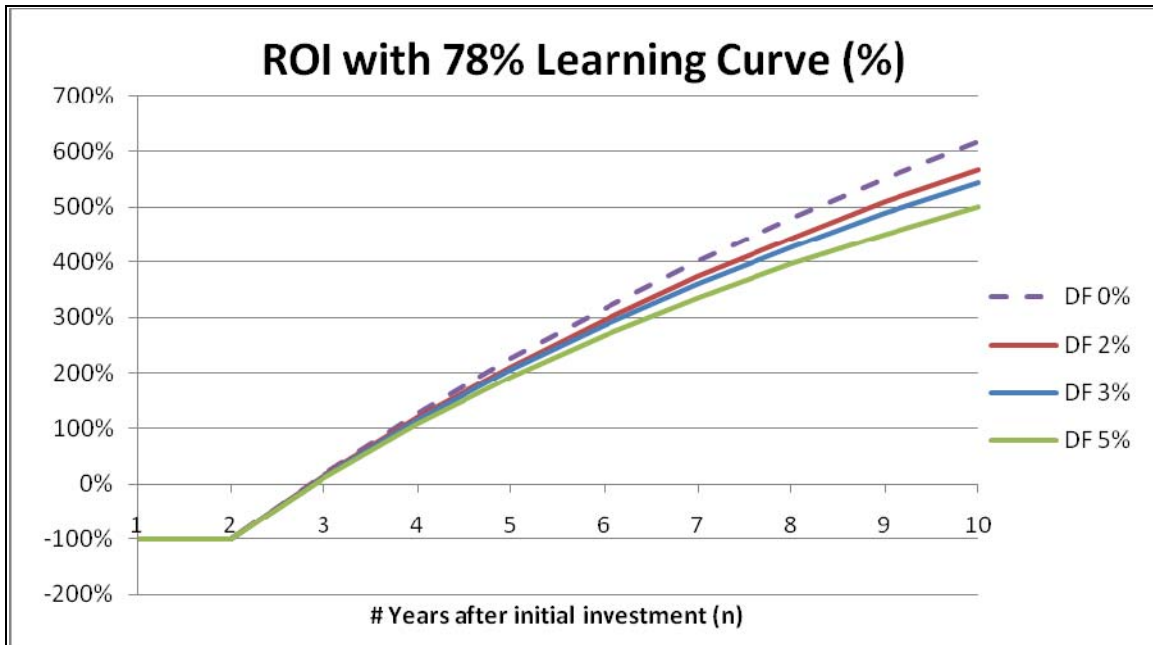


Figure 10. ROI with 78% learning curve & $X=1$.

At twice the standard error for b , the learning curve is 78% (i.e., $2^{-0.535+0.172} \approx 0.78$). At this learning curve, the investment breaks even within three years with an ROI between 500–610% over ten years, depending on the discount factor used.

c. **95% Learning Curve**

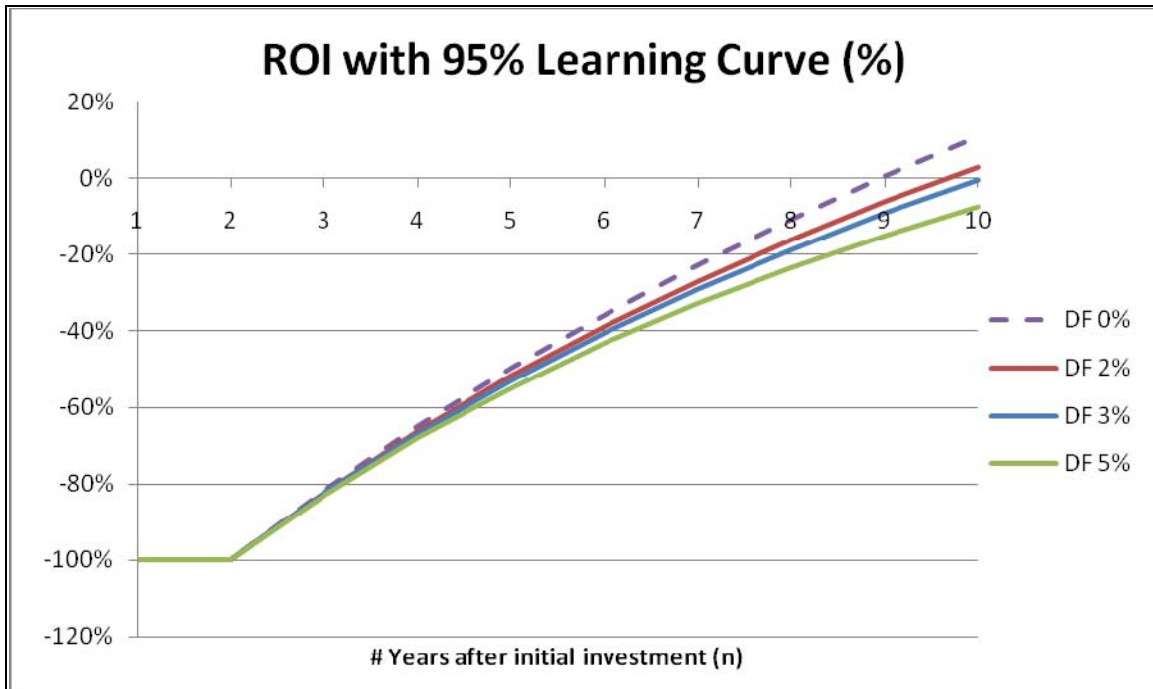


Figure 11. ROI with 95% learning curve & $X=1$.

Even with a learning curve as flat as 95% (i.e., combat fatalities drop by 5% for every doubling of time spent in theater), the system still returns a positive ROI after ten years with a discount factor lower than 3%. This means that at any value of learning curve flatter than 95%, the number of casualties attributed to the “learning effect” is too little to justify the investment.

2. Effectiveness of the Training

The base case assumes that training in FITE Facility-based Mixed Reality is equivalent to clocking the first month ($X=1$) of combat experience under less hazardous conditions. Suppose the various technologies in FITE could be seamlessly integrated such that the training effectiveness resulted in the equivalent of clocking two ($X=2$) months in theater; or the training turns out to be less effective than expected and only results in gaining the equivalent of half ($X=0.5$) month’s combat experience. Then, the sensitivity of the ROI, with respect to the base case and the break-even points, is presented in the following paragraphs.

a. $X=2$

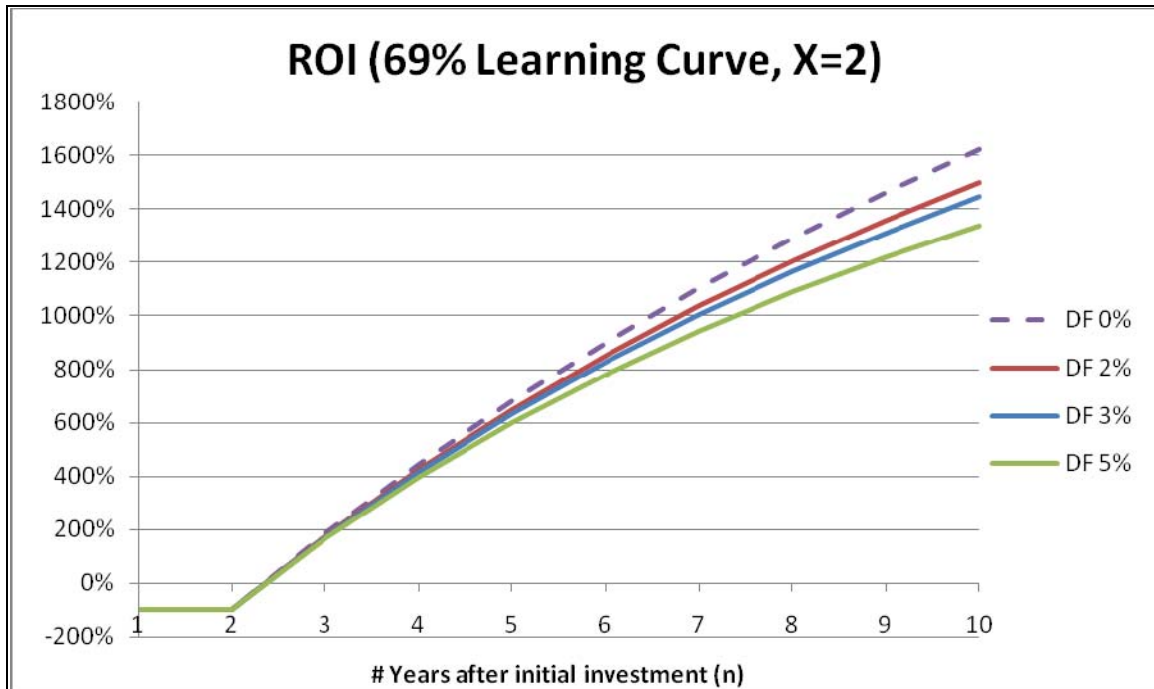


Figure 12. ROI with 69% Learning Curve & $X=2$.

At the baseline scenario with a 69% learning curve, the investment breaks even between two and three years with an ROI between 1300–1600% over ten years. Doubling the effectiveness does not have the proportionate effect on the ROI. A possible reason for this observation is that with a steep learning curve, the bulk of casualties occur in the initial months of deployment, and the additional increase in effectiveness results in a less than proportionate increase in the number of combat fatalities avoided. Even so, an effectiveness of $X=2$ still gives a 33% higher ROI over the base case. And if the learning curve is as flat as 97%, the investment may still break even over ten years, if no discount factor is used (see Figure 13)..

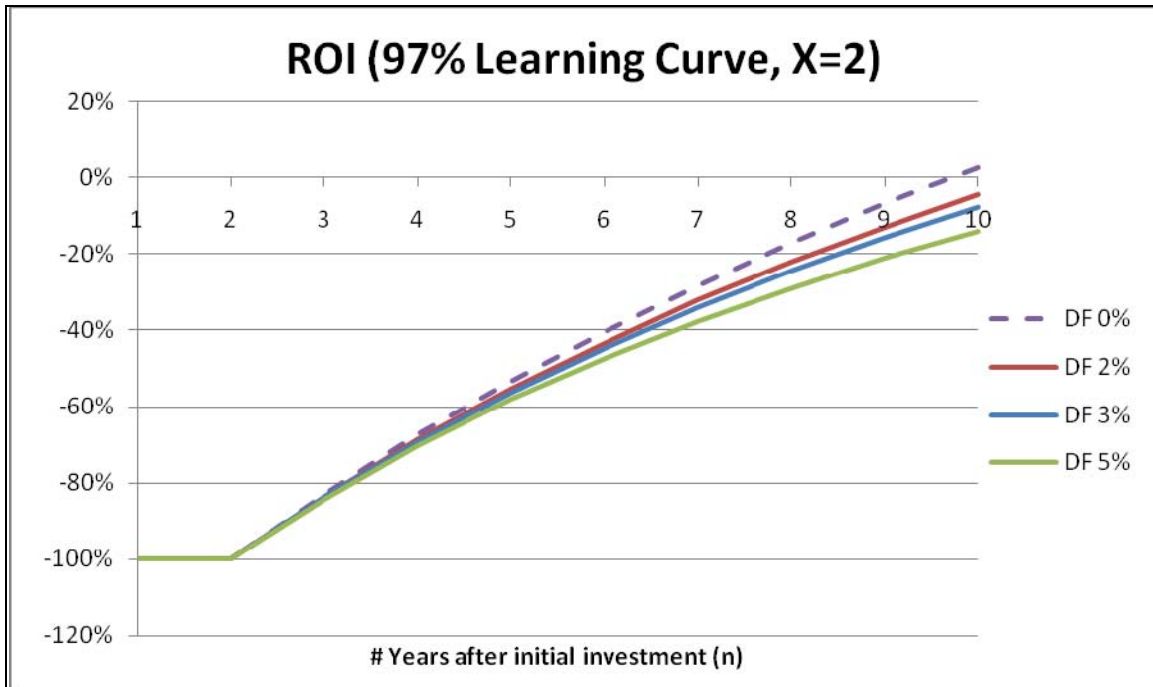


Figure 13. ROI with 97% Learning Curve & X=2.

b. X=0.5

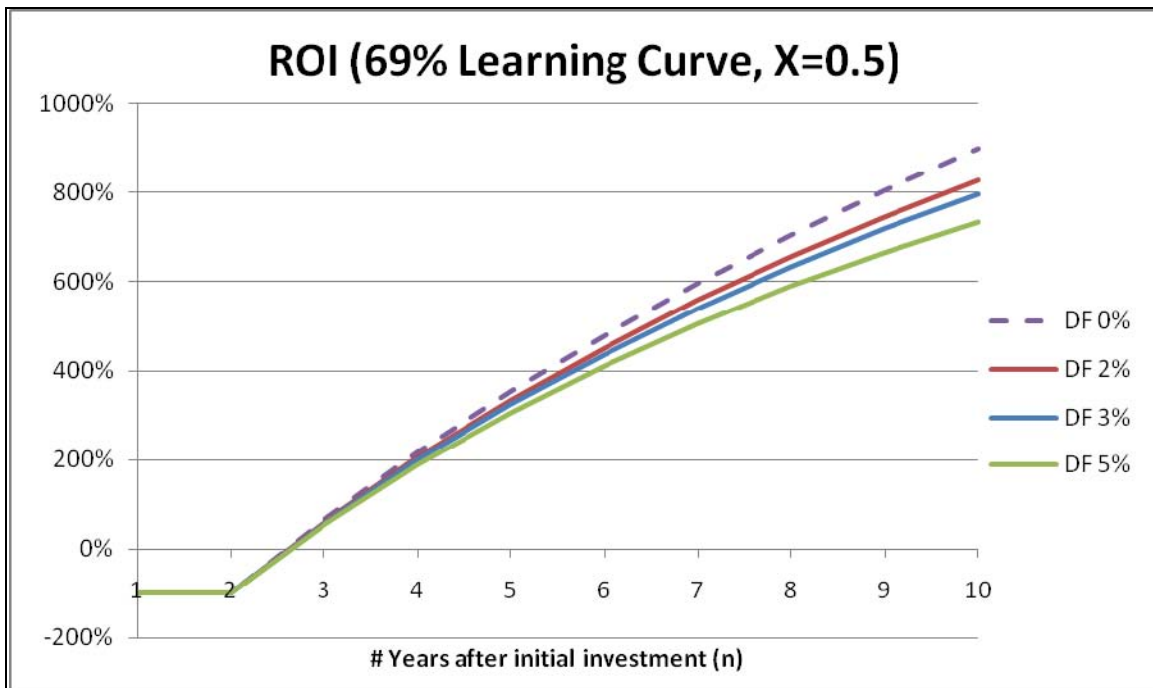


Figure 14. ROI with 69% Learning Curve and X=0.5

At 69% learning curve and a system that achieves half the baseline effectiveness (i.e., $X=0.5$), the investment still breaks even between the second and third year with an ROI between 730–900% over ten years (Figure 14), compared to 1000–1200% for the base case. The system breaks even for $X=0.5$ with a learning curve as flat as 93% (Figure 15).

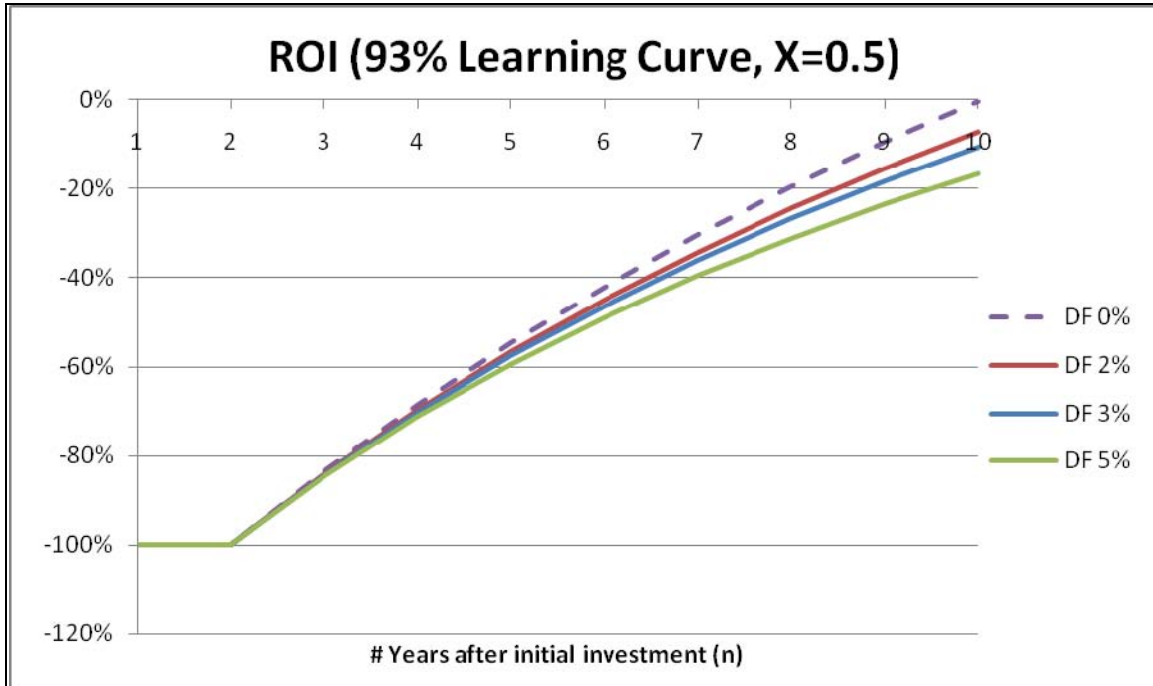


Figure 15. ROI with 93% Learning Curve & $X = 0.5$.

IV. CONCLUSIONS AND RECOMMENDATIONS

Although a human life cannot be measured by its monetary value alone, the need to measure the return on investments makes it necessary to put an economic value on life. If FITE Facility-based Mixed Reality performs as suggested, the analysis shows that it is clearly a worthwhile investment with an ROI between 1000–1200% over a wide range of input parameters. The high estimated ROI also provides a significant margin on the upside to accommodate for costs to transit FITE to operational deployment.

A. SENSITIVITY ANALYSIS

1. Slope of the Learning Curve

The influence of the learning curve slope on ROI, at $X=1$, demonstrates that even if the real learning curve is as flat as 95% in the operating environment, investments in the FITE Facility-based Mixed Reality will likely break even within the lifetime of the system. In other words, the investment is still worth making if the real effect of experience on combat fatalities is nearly one-sixth (i.e., 5% reduction for every doubling of time spent) of that shown by the Vietnam War combat fatality data (i.e., 31% reduction for every doubling of time spent), provided the FITE training effectively substitutes for one month of combat experience. Over the system lifetime, the ROI drops by half (1200% to 610%) when the learning curve is flatter by 9% (69% to 78%), indicating that ROI is sensitive to the slope of the learning curve.

2. Effectiveness of the System

As training effectiveness is doubled from $X=0.5$ to $X=1$, and again from $X=1$ to $X=2$, the ROI at 69% (base case) learning curve increased by approximately 33% in each case. Furthermore the investment breaks even at learning curves of 93% (for $X=0.5$) and 97% (for $X=2$) respectively. This result suggests that ROI is less sensitive to training effectiveness. While increasing system effectiveness increases ROI over system lifetime, due consideration must be given to the cost of adding features that improve training realism.

B. RECOMMENDATION

Considering only the number of fatalities avoided, the investment in the FITE Facility-based Mixed Reality clearly offers the Department of Defense attractive Returns on Investment. This is by no means the only benefit of FITE. The military also stands to gain from intangibles such as improved public opinion at home due to fewer fatalities, as well as better cooperation from local populations leading to less support for extremists. If an economic value could be placed on these benefits, the returns would be even more substantial. Therefore, there is a strong case to justify continued investment in FITE.

C. FURTHER RESEARCH

As a comparison to the conclusions in this thesis, a different research approach could be taken. The investment in FITE could be compared to the cost of fulfilling the same training objectives without using any virtual reality components.

Another possible area for further study would be from data that relates combat fatalities against the number of missions undertaken. This would give a more direct relationship between casualty numbers and combat experience while providing a better performance indicator with which to measure the training outcome. This research could be taken a step further by examining what other impact FITE Facility-based Mixed Reality training may have on soldiers' combat effectiveness and how these may be quantified.

APPENDIX A: FITE DESIRED CAPABILITIES AND METRICS

Desired Capability	Task	Attribute / Condition	Measure	Metric	Baseline as of 2009	Targeted Threshold for Aug 2010 (i.e., OD2)	Objective (i.e., stretch target, not required for JCTD success)
Training capability with integrated, interoperable, immersive elements	Replicates elements of the visual, audio, tactile, olfactory, effects and conditions of the battlefield across the full spectrum of operations in order to improve cognitive skills	Visual: Natural Field of View (FOV), Natural Field of Regard (FOR), Resolution, Natural method for changing FOV.	Objective measure of what the system has vs. the average human sense is. Subjective assessment by trainee	Percentage of trainees that report that sensory stimulation in the training environment is sufficient to accomplish training tasks	Home Station MOUT facility	75% report that the environment is sufficient to train the tasks and superior to live training	90% report that the environment is sufficient to train the tasks and superior to live training
		Audio: Hear sounds from all directions, and properly attenuated	Objective measure of what the system has vs. the average human sense is. Subjective assessment by trainee	Percentage of trainees that report that sensory stimulation in the training environment is sufficient to accomplish training tasks	Home Station MOUT facility	75% report that the environment is sufficient to train the tasks and superior to live training	90% report that the environment is sufficient to train the tasks and superior to live training
		Tactile: Feel operational environment effects	Objective measure of what the system has vs. the average human sense is. Subjective assessment by trainee	Percentage of trainees that report that sensory stimulation in the training environment is sufficient to accomplish training tasks	Home Station MOUT facility	75% report that the environment is sufficient to train the tasks and superior to live training	90% report that the environment is sufficient to train the tasks and superior to live training
		Olfactory: Smell operational environment effects	Objective measure of what the system has vs. the average human sense is. Subjective assessment by trainee	Percentage of trainees that report that sensory stimulation in the training environment is sufficient to accomplish training tasks	Home Station MOUT facility	75% report that the environment is sufficient to train the tasks and superior to live training	90% report that the environment is sufficient to train the tasks and superior to live training
	Team members exercise close combat tasks in a realistic fully immersive training environment that creates and reinforces complex (tactical and human dimension) decision making skills under stressful conditions	Team members exercise close combat in virtual environment	Subjective assessment of trainee and trainer	The percentage of the trainees reporting adequacy	Capability doesn't exist	75% report that the environment is sufficient to train the tasks and superior to live training	90% report that the environment is sufficient to train the tasks and superior to live training
		Virtual environment induces sufficient stress in the trainee	Subjective assessment of trainee and trainer	The percentage of the trainees reporting adequacy	Capability doesn't exist	75% report that the environment is sufficient to train the tasks and superior to live training	90% report that the environment is sufficient to train the tasks and superior to live training
	Provides culturally realistic, reactive, dynamic, synthetic entities that allow realistic interaction within COE (team members, higher headquarters, adjacent units, supporting arms, civilians and OPFOR)	Virtual Environment portrays individuals with sufficient fidelity to allow trainee to exercise culturally realistic training	Subjective assessment by trainee and trainer	% of trainees and trainers reporting adequacy	Capability doesn't exist	75% report that the environment is sufficient to train the tasks and superior to live training	90% report that the environment is sufficient to train the tasks and superior to live training
	Repeatable and rapidly reconfigurable scenarios and environment to include home station	Unit Leader can rapidly reconfigure scenarios and physical settings	Is minimal time lost during reconfiguration	Objective measure of time for reconfiguration	100% repeatable and limited ability for reconfiguration	100% repeatable and near real time reconfigurable	100% repeatable and near real time reconfigurable
	Real-time, physically accurate representation of ballistic effects	Virtual characters respond realistically to being hit by small arms fire	Subjective assessment by trainee and trainer	% of trainees and trainers reporting adequacy	Capability doesn't exist	75% report that the environment is sufficient to train the tasks and superior to live training	90% report that the environment is sufficient to train the tasks and superior to live training

Table 11. Integrated, Interoperable, Immersive Training Environment (From [14])

Desired Capability	Task	Attribute / Condition	Measure	Metric	Baseline as of 2009	Targeted Threshold for Aug 2010 (i.e., OD2)	Objective (i.e., stretch target, not required for JCTD success)
Trainee feedback	Provide feedback instantaneously and in-stride	Real time, realistic portrayal of battlespace and entities	Actions are observed or recorded	Awareness of each trainees actions	Limited to observation by trainer	At least 50% of trainees actions are able to be critiqued immediately by trainer (as appropriate)	At least 90% of trainees actions are able to be critiqued immediately by trainer (as appropriate)
	Replicate kinetic and non-kinetic interactions for trainee(s)	Realistic portrayal of kinetic and non-kinetic battlespace	Trainees receive sensory stimulation when hit by bullet Trainees are able to modify the behavior of characters by their actions	Trainee reports knowledge of injury to self and teammates. Trainee reports that they are able to effect characters actions	Observation of SESAMS/UTM marks if used / Not possible	75% of engagements are reported properly	90% of engagements are reported properly

Table 12. Trainee Feedback (From [14])

Desired Capability	Task	Attribute / Condition	Measure	Metric	Baseline as of 2009	Targeted Threshold for Aug 2010 (i.e., OD2)	Objective (i.e., stretch target, not required for JCTD success)
Joint Enablers	Trainee request, control, and coordinate supporting arms and Intelligence, Surveillance, and Reconnaissance (ISR) within the training scenario	Realistic portrayal of requesting joint enablers / combined arms integration	Call for fire or CAS can be sent over simulated comm. nets to the firing agency	Calls for fire or CAS are answered	Supporting arms requests for fire are not represented	Requests for fire are submitted, answered, and coordinated	Requests for fire are submitted, answered, and coordinated

Table 13. Joint Enablers (From [14])

Desired Capability	Task	Attribute / Condition	Measure	Metric	Baseline as of 2009	Targeted Threshold for Aug 2010 (i.e., OD2)	Objective (i.e., stretch target, not required for JCTD success)
Collective After-Action Review	Record and be able to playback each entity's movements, orientation, and communications	Accurate and automated playback	All Kinetic, verbal, and gestural interactions are recorded and analyzed in an automated process	All Kinetic, verbal, and gestural, interactions are available for review with automated analysis upon completion of the training evolution	Entities movement, orientation, and communications is currently not captured.	At least 50% of kinetic, verbal, and gestural interactions are recorded, analyzed, and available for review	90% of kinetic, verbal, and gestural interactions are recorded, analyzed, and available for review upon completion of training
	Provide rapid trend analysis	Timely analysis of performance trends	Comparison to doctrinal TTP's and correlation to best practices	Trends identified and behaviors changed or TTP's modified	Not currently available	System will record all exercises and allow for trend analysis	System will record all exercises and allow for trend analysis

Table 14. Collective After Action Review (From [14])

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APPENDIX B: RESULTS OF LINEAR REGRESSION ON VIETNAM WAR COMBAT FATALITIES DATA

Duration (mth)	# Fatalities (pax)	Cumulative Duration (N)	Cum. Fatalities	Cum. Ave Fatalities (CAF)	ln(N)	ln(CAF)
3	15,194	3	15,194.00	5,064.67	1.099	8.530
3	9,502	6	24,696.00	4,116.00	1.792	8.323
3	6,394	9	31,090.00	3,454.44	2.197	8.147
3	2,283	12	33,373.00	2,781.08	2.485	7.931
6	829	18	34,202.00	1,900.11	2.890	7.550

SUMMARY OUTPUT

<i>Regression Statistics</i>	
Multiple R	0.962696303
R Square	0.926784171
Adjusted R Square	0.902378895
Standard Error	0.117762649
Observations	5

ANOVA

	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	1	0.52663536	0.52663536	37.97474618	0.008600358	
Residual	3	0.041604125	0.013868042			
Total	4	0.568239485				
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	9.203663115	0.187291675	49.14080186	1.85565E-05	8.607617414	9.799708815
X Variable (ln N)	-0.529295688	0.085891644	-6.162365308	0.008600358	-0.802641233	-0.255950142

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